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**MOVEMENT ANALYSIS OF THE PERFORMANCE OF A
SIMPLE PERCEPTUAL-MOTOR TASK UNDER VARIOUS CONDITIONS**

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APRIL 1954

WRIGHT AIR DEVELOPMENT CENTER

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Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report is based upon research which was conducted by the University of Louisville under USAF Contract No. AF 33(038)-10196. The contract constituted a sub-project under a project identified by Research and Development Order 694-17, "Design and Arrangement of Aircraft Controls." The sub-project was 694-17C, "Factors Influencing Speed and Accuracy of Manual Movement." The contract was administered by the Psychology Branch of the Aero Medical Laboratory, Directorate of Research, Wright Air Development Center with Dr. W. C. Biel, Mr. M. J. Warrick and Mr. R. L. Morgan acting as Project Engineer during successive phases of the contract. The data were collected by Mr. W. F. Lowe, analyzed by Mr. Gene Farr and Dr. R. B. Ammons. Film records were developed and printed by the Photographic Services Center, Wright Air Development Center.

ABSTRACT

Techniques are available for the analysis of complex motor activities such as industrial assembly operations; and, the application of these techniques has contributed to the development of both improved methods of operation and more effective training programs. Despite their potential value, techniques have not been perfected, as yet, for the analysis of a continuous, skilled response. The present experiment represents an attempt to determine the value of motion pictures as a technique for recording, analyzing and classifying the movements which are made during the performance of a continuous, perceptual-motor task.

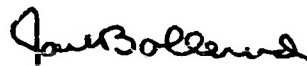
A study was made of changes in rotary pursuit performance due to duration of practice, introduction of rest periods, increased accuracy requirements, and increased rate requirements. Motion picture recordings were made, and all movements were classified into categories or types. An evaluation of the results indicated that they could be described simply in terms of changes of the movements from maladaptive and inaccurate to adaptive and accurate. It was proposed that the less effortful the particular conditions of the task, the more nearly performance will approach the optimum, with the less-adaptive movements dropping out. Also, it was suggested that the more effortful erroneous movements drop out more rapidly than the less effortful ones.

It was concluded that motion picture recordings are a feasible technique for the analysis of at least rather simple, continuous responses. This technique should be useful in further investigations of skilled performance and in programs which are designed first to find, and then to teach, the optimally effective methods of performing certain continuous tasks.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:



JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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INTRODUCTION

Micromotion study has been used systematically and with reasonable success by industrial engineers since the Gilbreths for the practical study of perceptual-motor tasks. Essentially, motion study involves (a) making a semipermanent record of a particular activity, (b) analyzing the activity into a meaningful set of components, and (c) studying the performance of these components with an eye to greater efficiency. The recording method found most satisfactory by the Gilbreths and their successors in the field was the motion picture, often taken at high speed so that it could be slowed down during subsequent study and analysis of the movements. Records have also been made in other ways, as for example, by making photographic time exposures of the movements of lights attached to various parts of the body, or making clock or polygraph records of the total duration of some movement completing an electrical circuit.

The problem of developing a meaningful set of components into which to analyze an activity is not too difficult where the activity is rather complex, as in the case of industrial assembly operations. The Gilbreths proposed a set of seventeen classes of motion elements ("therbligs"), including search, select, grasp, transport empty, transport loaded, etc. Although other workers have suggested different classifications, those of the Gilbreths are still the most widely used.

The study of the component movements or movement elements is carried on by timing their duration and by examination (usually subjective) of their amplitude and direction in relation to the rest of the task. A more extended discussion of the process of motion analysis than is here necessary can be found in books dealing with time and motion study (e.g., 5). Suffice it to say that once such an analysis has been made it is possible to set up a standard method of performing the task and aim training programs in its direction.

Many motion studies have been concerned with the skilled performance of some particular "complex" behavior (involving numerous therbligs) as affected by mechanical conditions, e.g., the putting of pegs into holes with varying tapers. Some studies have dealt with a "simple" (one therblig) movement, such as "transport loaded", e.g., carrying a pen from its desk set to the letter to be signed, or moving a slider to a point on a scale. Perhaps because of the simple elements involved and their presence at a high level of learning in most Ss, there has been little study of the process of actually learning to make these simple movements.

Perhaps the most widely studied simple movement has been rotary pursuit. The task calls for keeping the point of a stylus on a circularly revolving target set flush with the top surface of a phonograph-like turntable. This task was used successfully as a test for selection of airplane pilots during World War II (11), and is sensitive to a wide variety of variables significant in training programs with much more complex skills. Unfortunately, only one aspect of rotary pursuit has been extensively investigated, the total time on target for an interval of five or more seconds, although some information is available about the duration of the "hits" (individual movements keeping the stylus continuously in contact with the target) and their distribution in time.

It is known that the course of rotary pursuit learning defined as time on target is affected as follows by increased accuracy requirement, increased rate requirement, amount of practice, and temporal distribution (spacing) of practice

periods. Increased accuracy requirements: Decrease in size of target is accompanied by a decrease in total time of stylus-target contact roughly proportional to area of target, and overall slower improvement in performance (9). Increased rate requirement: Increase in rate of target rotation leads to less total stylus-target contact time and slower improvement in performance (9). Amount of practice: As the subject (S) practices longer, his total stylus-target contact time per unit time increases (2, 8, 9, 10), unless a rest of five minutes or longer is introduced (2, 10) and followed by relatively massed practice. Number and mean duration of contacts per unit time increase with practice (3). Temporal distribution of practice periods: If duration of practice periods is kept constant, and time between trials is increased from zero, total time of stylus-target contact increases at least until the rest periods are of two minutes duration (2, 8, 10). Number and mean duration of contacts increase more rapidly and are greater with distributed than with massed practice (3, 4).

We have seen that relatively complex skills can be analyzed into components suitable for consideration in training programs. Perhaps it is also possible to analyze more continuous, skilled responses into components and thus determine the optimal procedure for their performance. And, with precise knowledge of results, an operator could be trained to eliminate inadequate movement components while adopting more efficient movements. Since the analysis of complex activities has been valuable, there is reason to expect comparable value from techniques for the analysis of continuous skilled movements.

There is another potential value of a method for the analysis of continuous perceptual-motor activities. These activities are sensitive to the effects of such variables as practice, distribution of practice, and rate and accuracy requirements. By developing a method for the analysis of continuous skills we could set up the basis for determining the effects of these variables much more precisely than when only the results of "successful" component responses are studied. The availability of more detailed information concerning training variables undoubtedly would facilitate the development of optimally effective training situations. Although the information obtained from one type of continuous task may not be applicable to other tasks, it is hoped that eventually the analysis of such tasks will indicate common response components and areas where wide generalization of information is permissible.

PROBLEM

The purpose of the present study was to develop a reliable method of recording and classifying movements during rotary pursuit, and to use this method to study changes in rotary pursuit performance due to duration of practice, introduction of rest periods, increased accuracy requirements, and increased rate requirements.

METHOD

Subjects:

A total of 64 male, undergraduate college students served as Ss. All were volunteers, naive to the apparatus; none suffered from serious visual or motor defect. No Ss failed to complete the experiment.

Apparatus:



Figure 1. Layout of Apparatus

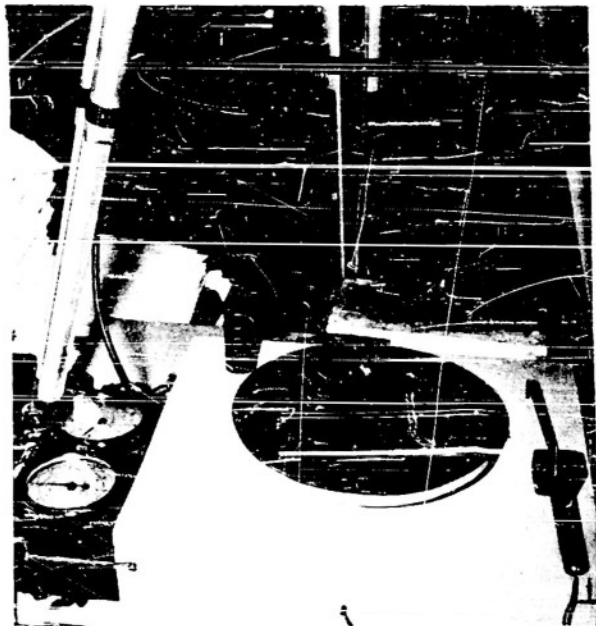


Figure 2. Closeup of Turntable and Accompanying Apparatus

The following pieces of apparatus were used: stylus, turntable, timers, a neon signal bulb, camera with tripod, photoflood lights with clamps, a control unit, and a film viewer. The stylus was hinged in the middle to prevent S's putting pressure on the tip. The hinged section was approximately six and a half inches in length and was tipped with silver. Figures 1 and 2 picture the stylus along with other pieces of apparatus. A more detailed description of the stylus has been published elsewhere (1). The turntable was a circular black plastic disc 11 inches in diameter mounted on a phonograph turntable and turned by a variable speed phonograph motor. The 1/4-in. and 3/4-in. brass targets were set flush with the turntable surface in interchangeable sectors, with their centers 3 1/4 in. from the center of the turntable. The turntable arrangement has also been described in more detail elsewhere (12).

Two .001-min. 6V DC Standard Electric timers were used. Both were set on the side of the rotor box, facing upward toward the camera, as shown in Figures 1 and 2. One ran continuously during practice periods, providing a check on the duration of these periods and on the rate of revolution of the turntable. The second timer was wired in the circuit with the stylus and target, so that contact between them would cause it to operate, and with the neon signal bulb which indicated stylus-target circuit completions for photographic purposes but was shielded so that the S could not see it. The circuit has been described in detail elsewhere (7). Basically it consisted of an electronic relay system which allowed either 6V DC or 110V DC to operate the neon bulb and timer.¹

The camera, which had a 17 mm. wide angle lens and was capable of taking pictures at the rate of 16, 32, or 64 per second, was mounted on a tripod in a position directly over the center of the turntable, pointing down toward it. The lens and the turntable surface were separated by a distance of 29 1/4 inches. Photoflood lamps were fastened to the tripod so as to illuminate the turntable without shining into S's face or the camera. A

1. Since the voltage in the stylus-target circuit was found to have no detectable effect on scores, it will not be mentioned further here.

simple switch arrangement served as a control to start and stop the turntable and the timer simultaneously.

A Bell and Howell Filmo 16 mm. viewer with 3 by 2 1/2 inch screen was used subsequently to view the film positives.²

Design:

The Ss were randomly assigned to one of the eight experimental conditions until there were eight Ss in each, or a total of 64. The eight conditions represented the eight cells in a 2x2x2 factorial design for testing the effects of three variables: (a) accuracy requirement, 1/4- or 3/4- inch target; (b) rate requirement, target revolving at 40 or 60 rpm; and (c) distribution of practice, 0 or 50 sec between successive 20-sec trials. It can be seen that scores for all 64 Ss can be used to make each major comparison, 32 in each of two groups. The Ss practiced a total of eight min, and photographic records at 32 pictures per sec were made of performance during the first and last 20-sec periods.

Procedure:

The Ss were tested one at a time. After having been assigned to an experimental condition, they were shown where and how to stand and how to hold the stylus. The target was to be followed with the stylus held in a loose grip with no attempt made to put additional pressure on the tip of the stylus. The operation of the camera was explained, and it was pointed out that it would be necessary to run the camera more than once during the practice period. Any pertinent questions were answered by rephrasing the instructions, the camera was started, then the turntable, timers, and neon light were switched on. When the camera had used up the 100 ft of film which its magazine would hold, it was turned off and reloaded. At approximately sixty-five sec from the end of practice the camera was started again. At both start and finish it was run only during actual practice with a safety margin before and after distributed trials (those separated by 50-sec rests). Verbatim instructions are given in the Appendix of this paper.

Scoring:

Before any analysis could be made, a method of classifying movements and of using the classification had to be developed. Several persons experienced with rotary pursuit listed all types of movements they could think of, then attempted to classify the movements made by Ss in several trial films studied with the film viewer. The list of movements was then revised into the final series given below and each type was defined as indicated.

1A. Pause. Stylus tip is touching the turntable but no movement can be detected in the stylus.

1B. Pause. Stylus is completely withdrawn from the turntable and cannot be seen on the film.

2. On target. Stylus tip touches brass target at some point. (This was scored primarily in terms of whether or not the neon signal bulb was on or off,

2. The Project Director wishes to express his gratitude for the excellent work done by the Photographic Services Center, Wright Air Development Center in developing and printing the films.

although in a few cases the physical contact was judged to have been made, even though the electrical circuit was not completed to turn on the neon bulb.)

3. Reverse movement. A movement of the stylus tip in a direction opposite to that in which the target is moving.

4. Tapping. Lifting the stylus tip from the turntable and dropping it in successive movements.

5. Looping. A circular motion of the stylus tip around the target at the rate of at least four revolutions during one complete revolution of the turntable. This must be within the 120 degree target segment.

6. Crossing. Moving the stylus tip from one side of the turntable to the other in an attempt to cut short to the target.

7. Criss-crossing. Moving the stylus tip from left to right and right to left in short strokes around the target area. Movement can also be up and down.

8. Circling outside. Moving the stylus tip circularly on the turntable, but more than 60 degrees from the target.

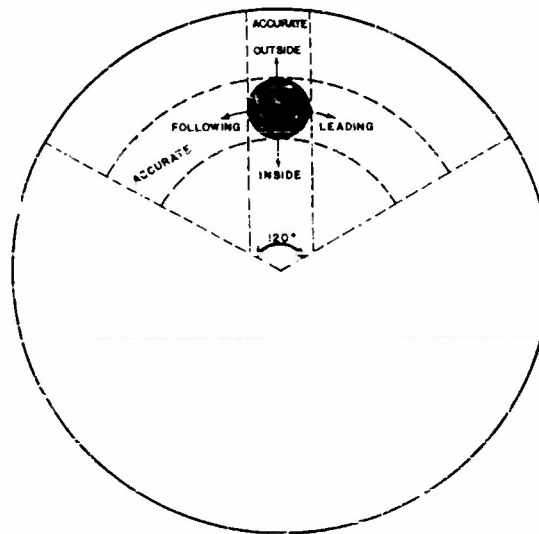


Figure 3. Schematic Drawing of Rotary Pursuit Turntable for Determining Types of Movements.

9. Leading, close approximate. Within 60 degrees of target. Not used as such.

9A. Leading outside. See Figure 3.

9B. Leading inside. See Figure 3.

9C. Leading accurate. See Figure 3.

10. Following. Within 60 degrees of target. Not used as such.
- 10A. Following outside. See Figure 3.
- 10B. Following inside. See Figure 3.
- 10C. Following accurate. See Figure 3.
11. Accurate. On a radius with the target, with a motion parallel to it.
Not used as such.
- 11A. Inside accurate.
- 11B. Outside accurate.
12. Straight line to target, but not crossing near center of rotor.
13. Unclassified.

For classification and scoring purposes, the films were observed frame by frame with a viewer. A plastic guide was placed with its center at the center of the turntable image, and with lines radiating from this center every 15 degrees, starting at the vertical upwards or 12-o'clock position. The resulting 24 sectors were numbered from 1 to 24 in a clockwise direction, 1 being the sector between the vertical upwards line and the first line to its right. See Figure 4 for a picture of the guide. The film was then read by making a running record of successive

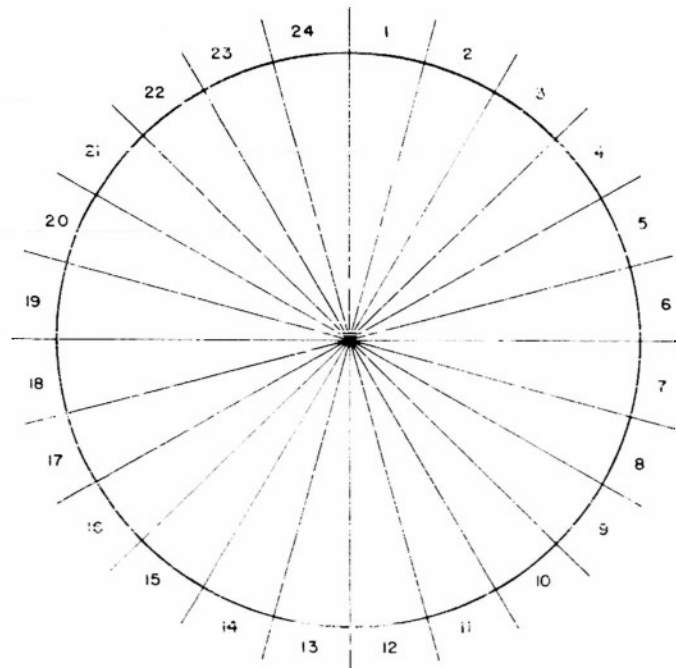


Figure 4. Schematic Drawing of the Scoring Guide for Use with Film Viewer.

movements and their durations in numbers of sectors. It should be noted that 20 revolutions were scored per trial for the 60-rpm Ss, while only $13 \frac{1}{3}$ were scored for the 40-rpm Ss, since trials were of 20-sec duration.

RESULTS

For each S, a tabulation of movements was made separately for the first and last 20-sec trials. This tabulation showed the number of each type of movement and the duration of each separate movement. From the tabulation certain other indices were derived. Total duration of a given movement was simply the total time it was being made during a 20-sec trial. Mean duration of a given movement was the average of the durations of separate movements of this type during a 20-sec trial. By averaging for all Ss in a certain group for a 20-sec trial, it was possible to obtain the mean number of each type of movement, the mean total duration of each type of movement, and the mean mean duration of each type of movement.

Reliability of Scoring of Movements:

It was possible to estimate the reliability of the scoring in two different ways. Two scorers scored a single 20-sec record independently. The results may be seen in Figure 5. The agreement as to total duration of each type of movement is obviously very high. The agreements on numbers and mean durations, components of total duration, are somewhat lower. The coefficients of profile similarity (6) were .30, .40, and .20 respectively for the three indices, indicating very high similarity, moderate similarity, and low similarity according to DuMas.

The second way of estimating the reliability of the scoring is by comparing groups which should have the same scores except for sampling errors. Figures 12, 13 and 14 show the performance of the distributed and massed practice groups for the initial 20 sec of practice. Since both groups presumably received the same treatment up to the end of this period, their scores should be essentially the same. It can be seen that the curves for mean total duration (Fig. 12) and mean number (Fig. 13) are very similar. The curves for the mean mean duration (Fig. 14) are somewhat less similar. The coefficients of profile similarity are respectively .39, .39, and .44, showing the same trend as the graphs. The reliability of the first two measures is adequate for group comparisons; however, the relatively low reliability of the mean duration scores suggests that some caution should accompany any attempt to assign significance to group differences on that score.

As this is primarily a descriptive study, no complicated statistics will be reported. Graphs will be used to present the findings, and only major findings will be mentioned and discussed. For this reason, no further comments will be made about movements 1B, 3, 4, 5, 6, 7, 12 and 13, whose incidence was very low. Findings concerning the remainder of the movements are organized into sections dealing with the effects of (a) accuracy requirements, (b) rate requirements, (c) distribution of practice, and (d) amount of practice. Because of the exploratory nature of the study and the relatively small number of Ss in the ultimate groups ($N = 8$), with but one exception, none of the many possible interactions have been calculated. The one exception is the interaction between the first three variables and amount of practice. For each variable two sets of graphs are presented — one for the initial 20-sec trial and one for the final 20-sec trial.

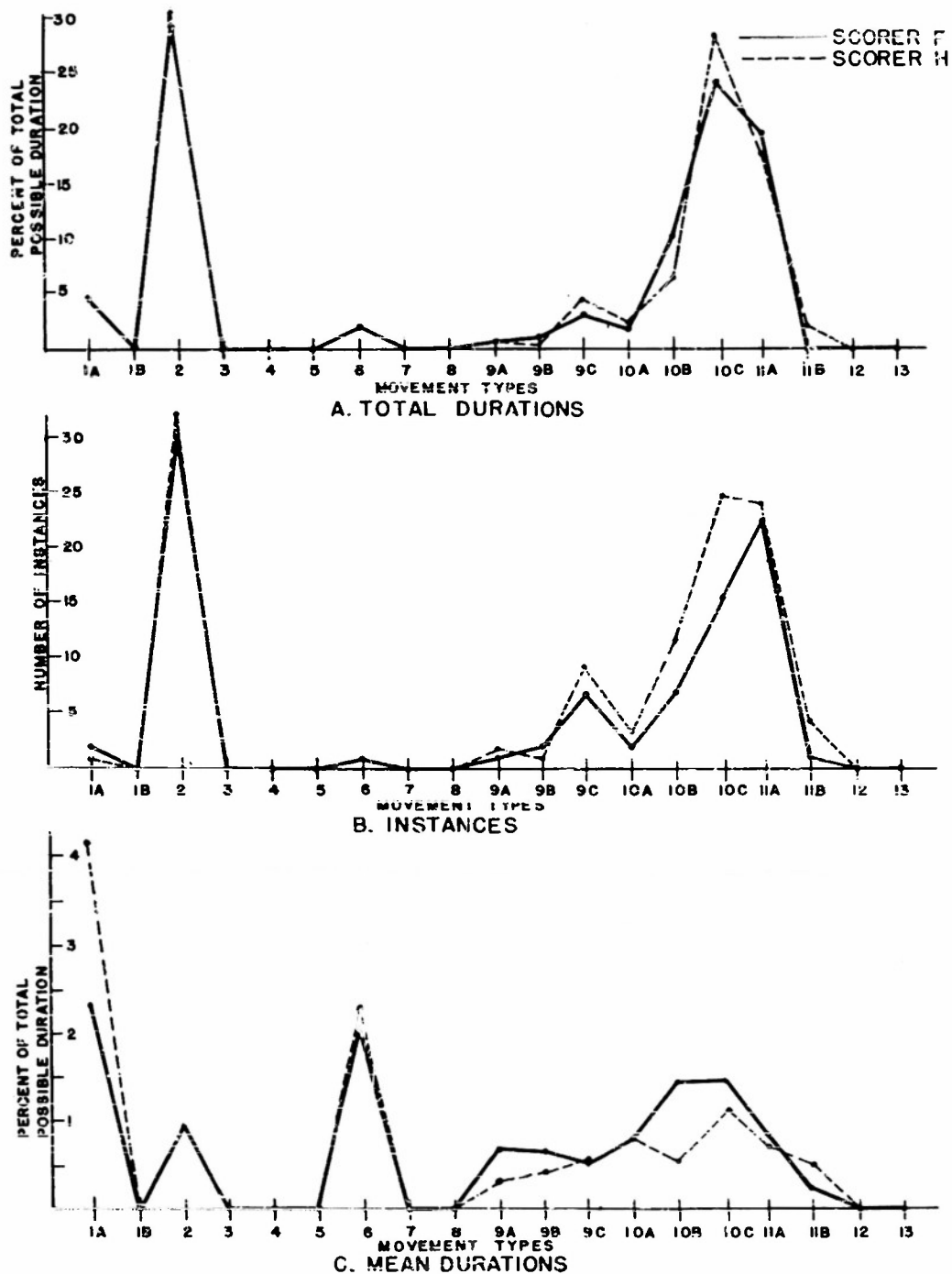


Figure 5. Scoring Reliability as Indicated by Agreement of Two Scorers Classifying Movements in One 20-sec Record for One S Practicing at 60 RPM.

Effects of Accuracy Requirements:

It will be recalled that 32 Ss practiced with a small (1/4-in.) target and 32 with a larger (3/4-in.) target. The effects of this variation in accuracy requirement on the various types of movement seem to be as follows. Results are given graphically in Figures 6, 7, and 8.

1A - Stylus tip on turntable but not moving.³ Groups show little difference in mean number, while 1/4-in. group persisted longer in each such movement and consequently accumulated a larger total duration.

2 - Stylus and target in contact. The group with the larger target showed a greater total duration, mean duration, and number. The increase with practice was proportionately greater for the group with the small target.

8 - Circular motion, but not near target. Greater total duration, greater number, and longer mean duration were found with smaller target. All three interacted with practice, the group with the larger target showing a greater drop.

9A - Leading outside, close to target. Greater total duration, greater number, longer mean duration with smaller target.

9B - Leading inside, close to target. Greater total duration and number with smaller target. Mean duration interacted with practice, the group with the smaller target showing an increase.

9C - Leading accurate. The 1/4-in. target group showed a gain in number, with no change in mean duration, thus an increase in total duration.

10A - Following outside. Greater total duration and number are found with smaller target. All three measures interact with practice, the group with the larger target showing a proportionately greater decrease in each.

10B - Following inside. Same as 10A.

10C - Following accurate. Mean duration was somewhat less with smaller target. Number and total duration interacted with practice, the group with the larger target showing a greater decrease.

11A - Accurate inside. Number and total duration interacted with practice, the group with the larger target showing proportionately less. Greater total duration and number are found with smaller target.

11B - Accurate outside. Same as 11A.

Effects of Rate Requirements:

As has already been explained, 32 Ss practiced with the turntable revolving at 40 rpm and 32 with it revolving at 60 rpm. Results of analysis are presented in Figures 9, 10, and 11. It should be remembered that these comparisons are based on 20 revolutions for the 60-rpm group and only 13-1/3 revolutions for the 40-rpm group. The most important rate effects were as follows.

3. Only rough descriptions of the movements will be given in this section. See Methods section for more precise descriptions.

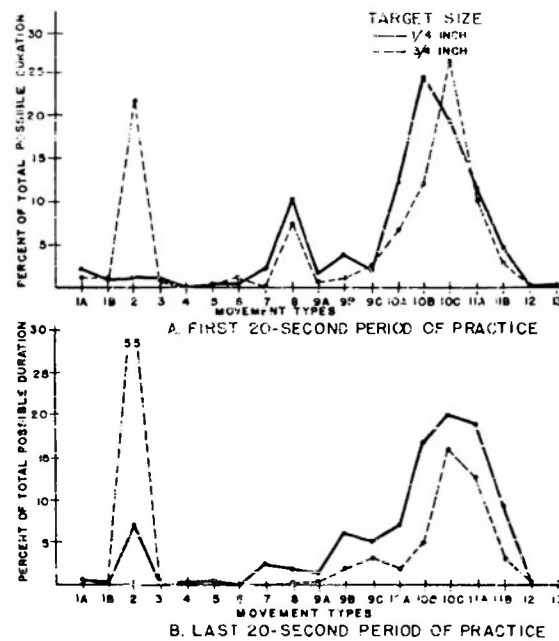


Figure 6. Effects of Accuracy Requirements on the Mean Total Duration of Various Types of Movements. Scores for 32 Ss are used in each curve.

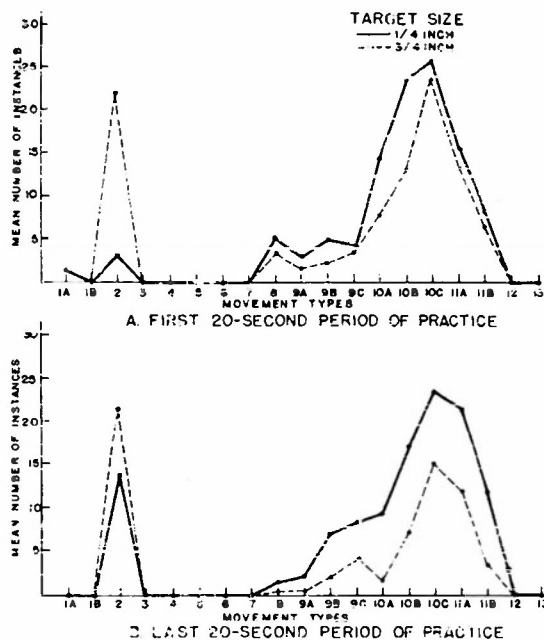


Figure 7. Effects of Accuracy Requirements on the Mean Number (Incidence) of Various Types of Movements. Scores for 32 Ss are used in each curve.

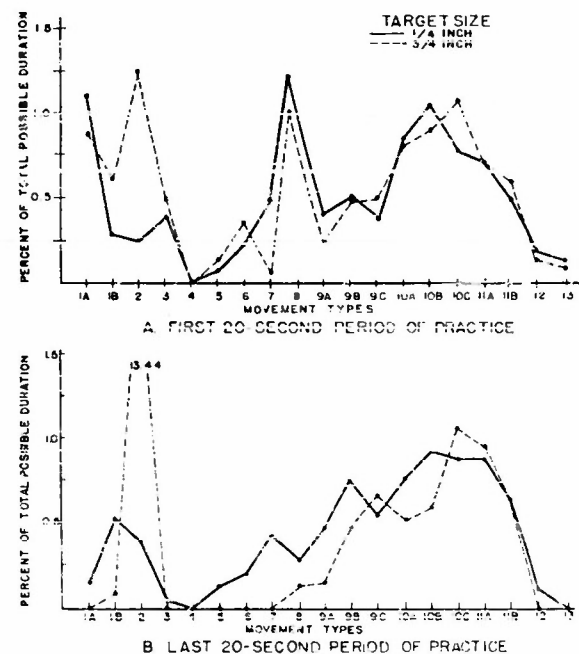


Figure 8. Effects of Accuracy Requirements on the Mean Mean Duration of Various Types of Movements. Scores for 32 Ss are used in each curve.

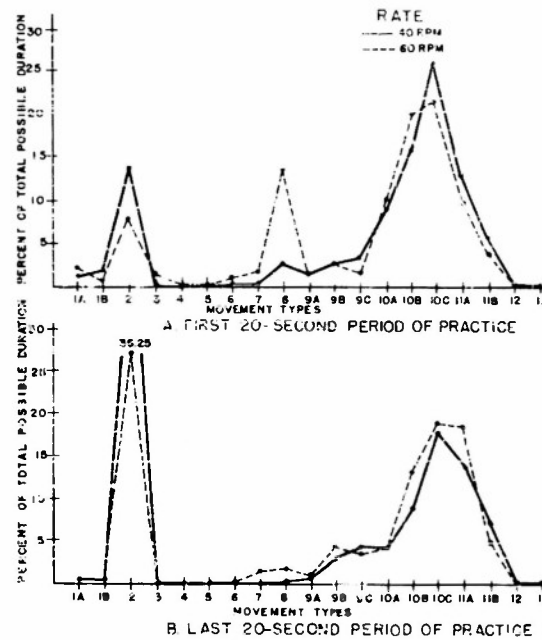


Figure 9. Effects of Rate Requirements on the Mean Total Durations of Various Types of Movements. Scores for 32 Ss Are Used in Each Curve.

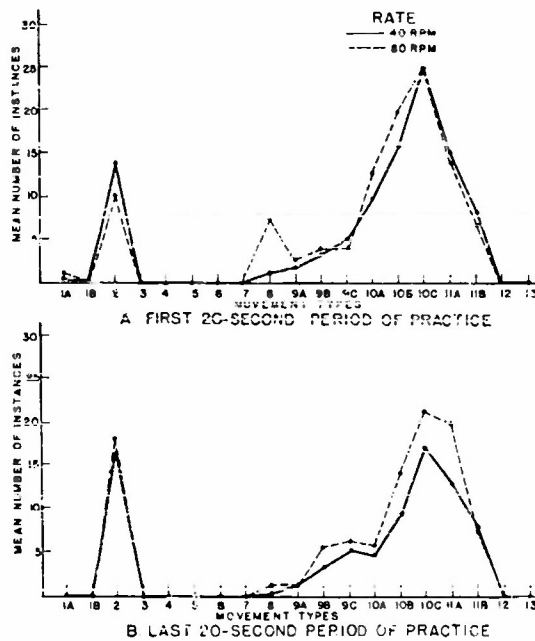


Figure 10. Effects of Rate Requirements on the Mean Number (Incidence) of Various Types of Movements. Scores for 32 Ss are Used in Each Curve.

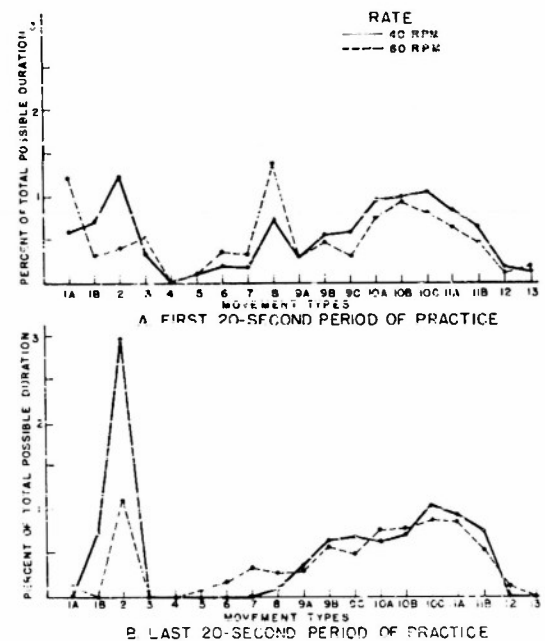


Figure 11. Effects of Rate Requirements on the Mean Mean Duration of Various Types of Movements. Scores for 32 Ss are Used in Each Curve.

1A - Stylus tip on turntable but not moving. This occurred only during first 20 sec. The 60-rpm group had the greater mean duration.

2 - Stylus and target in contact. The 40-rpm group was higher in total duration, but made a proportionately smaller gain with practice. The 60-rpm group made a proportionately larger gain in number and mean duration.

8 - Circular motion, but not near target. The 60-rpm group showed a greater total duration, number and mean duration.

9A and 9B - Leading outside and inside, respectively, close to target. Rate effect was quite small.

9C - Leading accurate. Rate had little or no effect on the indices. The 60-rpm group showed a greater relative total duration, number and mean duration after some practice.

10A and 10B - Following outside and inside, respectively. The 60-rpm group showed a greater total duration and number. During the first 20 sec the mean duration for the 40-rpm group is greater.

10C - Following accurate. The 60-rpm group showed a shorter mean duration. Number and total duration interacted with practice, the 40-rpm group decreasing proportionately more.

11A - Accurate inside. The 60-rpm group showed less total duration at the start but more at the end, less mean duration both times, and greater number at the end.

11B - Accurate outside. The 40-rpm group showed greater total duration than the 60-rpm group, but very similar number. Actually, the 40-rpm group displayed a larger number of instances per revolution, since there are fewer revolutions in a trial.

Effects of Distribution of Practice:

The design of the experiment was such that although all Ss practiced for 24 trials of 20 sec each, 32 Ss were allowed no rest between trials while 32 Ss were given rests of 50-sec duration. The results are presented graphically in Figures 12, 13, and 14.

It should be noted that the performance of the two groups should differ only by chance during the initial 20-sec period, since no differential rests had been allowed at that time. An examination of the graphs reveals rather large differences between the groups on the mean duration of various types of movements while a rather high degree of agreement exists for the other scores. As noted previously caution should accompany any attempt to assign significance to differences among mean duration scores.

The following is a description of some of the effects of the distribution variable.

1A - Stylus tip on turntable but not moving. Practically no instances.

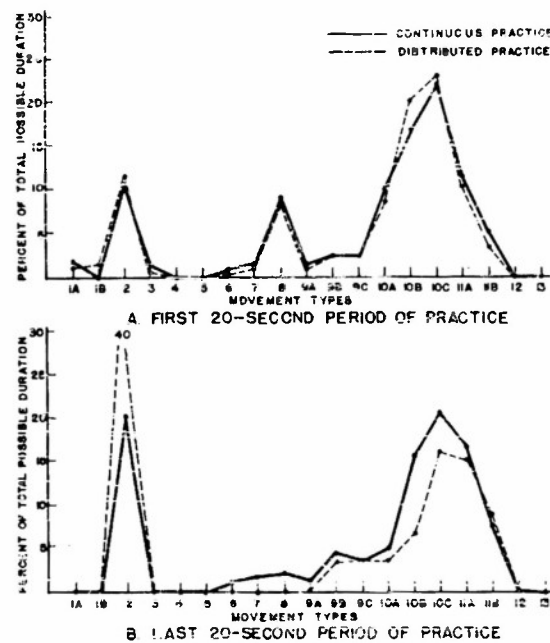


Figure 12. Effects of Temporal Distribution of Practice on the Mean Total Durations of Various Types of Movements. Scores for 32 Ss are Used in Each Curve.

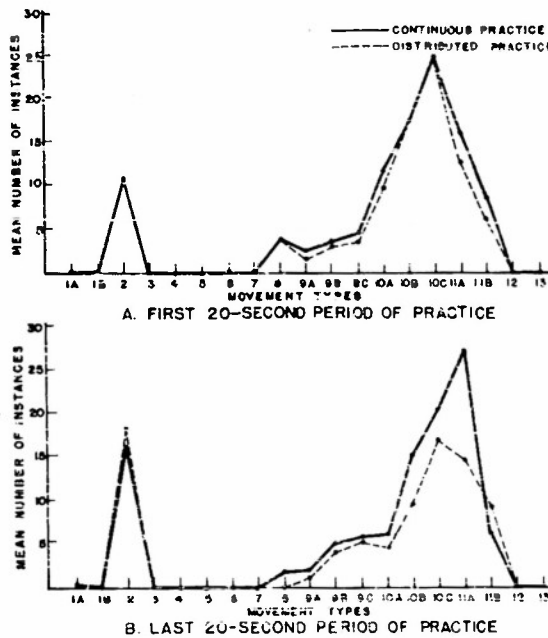


Figure 13. Effects of Temporal Distribution of Practice on the Mean Number (Incidence) of Various Types of Movements. Scores for 32 Ss are Used in Each Curve.

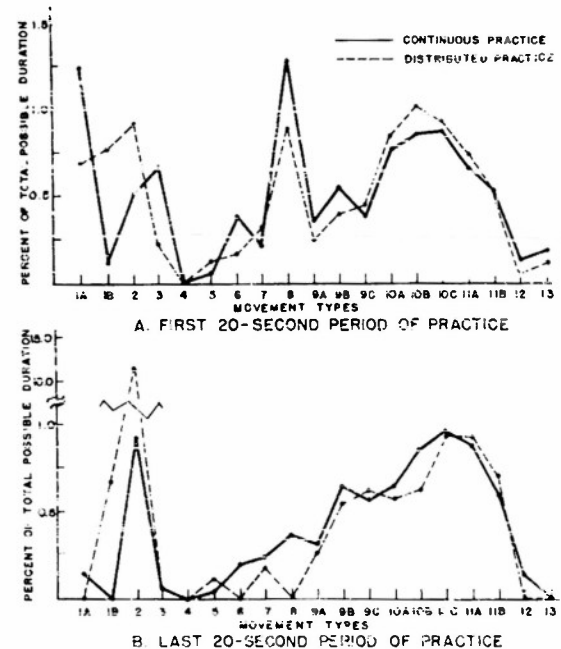


Figure 14. Effects of Temporal Distribution of Practice on the Mean Mean Duration of Various Types of Movements. Scores for 32 Ss are Used in Each Curve.

2 - Stylus and target in contact. By the end of practice, the distributed practice group showed much greater total duration, and mean duration.

8 - Circular motion, but not near target. During the last 20 sec of practice, only the continuous practice group showed an appreciable total duration, number, or mean duration of these movements.

9A, 9B, 9C - Leading - outside, inside, and accurate, respectively. These responses were little affected by this variable.

10A - Following outside. By the last 20-sec period, the continuous practice group showed a slightly greater total duration and number.

10B - Following inside. During the last 20 sec of practice the continuous-practice group showed a greater total duration, and a somewhat greater number and mean duration.

10C - Following accurate. The no-rest or continuous-practice group showed a greater total duration and number after practice.

11A - Accurate inside. During the last 20-sec trial the continuous-practice group showed a greater number, a slightly smaller mean duration, and a slightly greater total duration.

11B - Accurate outside. Somewhat greater total duration and number were shown by the distributed-practice group during the last 20-sec trial.

Effects of Practice:

The performance of all 64 Ss was measured during the first and last 20 sec of the 8-min practice period. By comparing performance during the two 20-sec trials, it is possible to estimate the effects of practice on the various types of movements. The major findings follow. It should be noted that interactions of practice and the other variables have already been mentioned in previous sections and accordingly are omitted from discussion in this section. Figures 6 through 14 show the total duration, number, and mean duration of types of movements at the start and finish of practice.

1A - Stylus tip on turntable but not moving. Decrease in total duration, number, and mean duration.

2 - Stylus and target in contact. Increase in total duration, number, and mean duration.

8 - Circular motion, but not near target. Decrease in total duration, number, and mean duration.

9A - Leading outside, close to target. Very slight decrease in total duration and number.

9B, 9C - Leading inside and leading accurate, respectively. Increase in total duration, slight increase in number and mean duration.

10A, 10B - Following outside and inside, respectively. Decrease in total duration, number, and mean duration.

10C - Following accurate. Decrease in total duration and number.

11A - Inside accurate. Increase in total duration, number, and mean duration.

11B - Outside accurate. Increase in total and mean duration.

DISCUSSION

The results of the present study are comparable with those in other studies only with respect to total duration of stylus-target contacts (time on target per trial) and to number and mean duration of contacts (hits), as pointed out in the introduction. These results agree in every case where comparison can safely be made with the results from other studies summarized there, which is taken to indicate that the method used for recording and measurement is adequate and that the groups are similar to groups in other studies.

It is apparent, however, that analysis of total duration, number, and mean duration of stylus-target contacts does not by any means exhaust the possibilities of the data. In fact, study of the figures and the results section of this paper reveals a confusing, perhaps even embarrassing, wealth of information. An attempt will now be made to organize and interpret these data to some extent.

The 18 types of movements used can be classified into several main groupings as follows:

- A. Maladaptive: - stylus tip not moving (1A)⁴, stylus withdrawn (1B), reverse movement (3), tapping (4).
- B. Semi-adaptive: - looping (5), crossing (6), criss-crossing (7), circling outside (8), straight to target but not across center (12).
- C. Adaptive: -
 - 1. Correct - stylus on target (2).
 - 2. Approximately correct -
 - a. Accurate - leading accurate (9C), following accurate (10C), inside accurate (11A), outside accurate (11B).
 - b. Others - leading outside (9A), leading inside (9B), following outside (10A), following inside (10B).

Since total duration of a movement is the most reliable index, and indirectly includes the number and mean duration, the discussion will be in terms of it.

Using the above grouping, changes with practice can be characterized rather simply. Although few maladaptive and semiadaptive responses occurred at any time, with practice the total duration of time for such responses was reduced to almost zero. Most of the adaptive movements which were not accurate also tended to decrease with practice; however, leading inside (9B) increased slightly with practice. The

4. All numbers in parentheses in the Discussion section refer to types of movements and none to references.

adaptive-correct and adaptive-accurate-approximately-correct movements gained in total duration, except in the case of following accurate (10C), which tended to drop out. It would seem that improvement takes the form of an increase in the precision of the circling movements necessary to perform the task and a decrease in other types of movements. The S who can make the basic movement but whose timing is "off", is well on the way to a higher performance level, as compared with the S who cannot make the basic movement.

Since practice, relative distribution of practice, relatively slower required rate of performance, and relatively larger target all appear to make the performance easier from the S's point of view, it is interesting to examine the effects of these variables on the total durations of the various types of movements. Quite naturally, all are associated with greater amount of time on target (2). All are also associated with less time during which the stylus was not moving (1A) or circling outside target area (8). Most of the easier task conditions also are accompanied by less time leading outside (9A), leading inside (9B), following outside (10A) and following inside (10B). Leading accurate (9C), following accurate (10C) and outside accurate (11B) show inconsistent results while inside accurate (11A) seems to have a greater total duration under the easier task conditions. Thus, considering the movements with an appreciable incidence, it seems that the relatively less effortful the particular variant of the task, the more nearly performance will approach the optimum, with less-adaptive responses dropping out. This fact, of course, adds little to previous information except to indicate that a description of performance under easier task conditions involves many aspects other than merely time on target scores. Although it was not the purpose of the present study, a description of the body movements which result in the various stylus positions would be both interesting and valuable.

It is interesting to note that the total duration for inside movements tends to increase more than the total duration of outside movements. Inside accurate movements (11A) show a greater absolute increase with practice than do outside accurate (11B). Leading inside movements (9B) increase with practice while leading outside (9A) decrease. Following outside (10A) and following inside (10B) both decrease but the decrease of the former is somewhat greater and more consistent. These differences are made greater by requiring more accurate or rapid performance and to a considerable extent by relative massing of the practice. Since outside movements involve more work than inside movements, the fact that outside movements drop out faster tends to support the hypothesis that the most effortful incorrect movements drop out faster than the less effortful ones. Another explanation is equally probable, however -- anything which makes the task more difficult will lead the S to make more movements "inside" the target since this position is nearer the center of movement of the target and hence a more likely spot from which to regain position on it. And, regardless of the task conditions, the number of inside movements should increase with additional practice because the S would discover the advantages of the inside position.

CONCLUSION

This study, an analysis of photographic recordings of a continuous, perceptual-motor response, allows several general conclusions. Three of these are:

- a. A reliable method of breaking down movements in learning and performing a simple perceptual-motor task has been developed.

b. This method has proven to be valid on common sense grounds in that results, where comparable, agree with those from other studies and the patterns of results seem reasonable in view of what is known about skills.

c. This method should be useful in further investigations of skilled performance and in programs which are designed first to find, and then to teach, the optimally effective methods of performing certain continuous tasks. Although a similar method has been used with much more complex skills, this is its first extensive application to a relatively simple "homogeneous" skill.

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APPENDIX

INSTRUCTIONS

"Have you ever practiced on equipment similar to this before?" (pointing to apparatus.) (If the answer is "yes", the subject is rejected. When the response is "no", the following instructions are given to the subject:)

"As I mentioned in the classroom, the Psychology Department at the University of Louisville has been helping the U. S. Air Force on a research program in motor skills. What you see before you is an arrangement of equipment which will help us to learn more about certain types of skills. You will notice that above the round black disk, there is a camera. During certain parts of your practice, the camera will record your performance.

"In a few moments the black disk will start turning. You will notice that on the disk there is a round metal target. You are to hold the stylus in your hand (hand subject the stylus) keeping the handle parallel to the floor. Grip the handle loosely, keeping your fingers back of the square collar. When the disk starts turning you are to keep the point of the stylus on the metal target as much as possible.

"Notice that on the left side of the disk housing, there are two clocks. These will record your performance at all times. It is very important that you try hard during your entire practice from start to finish. Remember that your performance will be recorded at all times -- even when the camera is not running.

"Be certain to hold the stylus by the handle in a loose, relaxed manner. The tip of the stylus should touch the disk but no attempt to push down on the point should be made.

"Are there any questions?" (Any questions pertaining to the instructions are answered, others deferred to the end of practice.)

"Ready now ---- do not begin until I say start." (The rotor starts -- two seconds later the camera starts and the subject is told:) "Start! Try very hard to stay on the target as much as possible."

(If the condition is a 20-second practice, 50-second rest condition, the subject, after each 20-second practice, is told:) "Stop and look away from the equipment but continue to hold the stylus." (At the end of 45 seconds rest, the signal,) "Get ready -- in position, (at 50 seconds) start at once."

(When the practice was completed, the subject was thanked for his help and invited to return with questions after all subjects had been filmed.)